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The Lighting of Hazardous and Corrosive Locations in Industrial Plants

By A. G. PALMER, B.Sc.(Eng.), A.M.I.Mech.E., A.M.Inst.Gas E., and W. E. HARPER, B.Sc.(Eng.), Ph.D., A.M.I.E.E. *(Member)*

Summary

At the twelfth session of the C.I.E. a committee was formed to study the lighting of hazardous and corrosive locations. This paper, by reviewing British practice in some detail, amplifies the report prepared by Great Britain as secretariat country. The nature of fire, explosion and corrosion hazards in industry are discussed in relation to lighting practice, the regulations are summarised and examples are given of modern practice.

Introduction

At the twelfth session of the C.I.E. in 1951 a new committee was formed, with Great Britain as the secretariat country, to study lighting in hazardous or corrosive locations. The following terms of reference of the committee were agreed:—

"To study and define situations in industrial and communal activities other than coal mines, in which the hazards due to the nature of the process or other circumstances require special consideration to be given to the lighting equipment and to its installation, and to study and report upon the means of providing safe and suitable lighting in such situations.

"The hazards may include dangers due to explosion or fire from gases, dusts, solids, liquids or vapours or any dangers which may result from corrosion.

"It is acknowledged that an insufficiently high standard of, or unsuitable, lighting may cause hazards quite independent of the hazards due to explosion, dust, corrosion and the like and the main function of the sub-committee is to deal with these aspects and not with those associated with unsuitable lighting."

A questionnaire has been sent to the member countries, the replies collated and a report prepared for the thirteenth meeting of the C.I.E.

This paper examines in more detail than is possible in the report problems of lighting industrial plants where hazards of fire, explosion and chemical attack are present; modern British practice is reviewed.

(1) General

In some factories where hazards are present the plant and processes allow normal planning of the lighting installation, although the presence of the hazards may limit the standard of lighting which can be achieved. In the basic industries, however, with which this paper is most concerned, there may be no "factory" in the accepted sense[1]; for example, the chemical plants shown in Figs. 1 and 2 are designed to operate in the open air. Good artificial lighting is, however, necessary for confident operation and safe movement at night on elevated walkways, platforms and stairways.

In some hazardous locations working conditions are bad owing to the heat, dirt and glare from the process; the intermittent vertical retort house shown in Fig. 3 is an example of such locations. Here loads of approximately six tons of coke at about 1,000 deg. C. are dropped into wagons before being taken away for quenching. The retort doors are some 10 ft. above floor level and are opened and closed hydraulically. Before they are opened and after they are closed the operator has to manipulate a number of latches set in the doors. The frames and doors are covered with tar deposits

Mr. Palmer is with the North Thames Gas Board and Dr. Harper with the Plastics Division of Imperial Chemical Industries, Limited. The manuscript of this paper was first received on December 3, 1954, and in revised form on January 7, 1955.

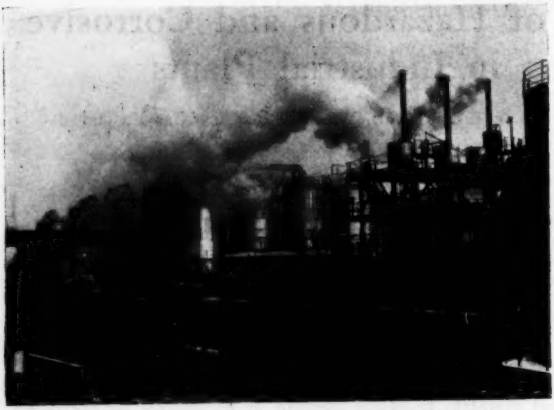


Fig. 1. General view of an outdoor nitric acid plant.

Fig. 2. Section of an outdoor kiln of a sulphuric acid plant with fittings grouped to illuminate machines.

Fig. 3. Bottom of intermittent vertical retorts showing coke being discharged.

which reduce visual contrast (Fig. 4), ventilation is bad, the ambient temperature is high, and when the coke is discharged the radiant heat is intense and the whole area is filled with fumes. In this plant the carbonising period is 11-13 hours, which means that one of the retorts is discharged about every quarter of an hour. The physical strain on the workers is considerable, and an important function of the lighting system in this and similar locations is to relieve that strain by facilitating recognition and improving confidence. Sometimes, as in this plant, it is not possible to provide the standard of lighting which the location and tasks demand; the engineer can only do the best possible within the limits imposed by the construction and operation of the plant.

These examples indicate the variety of problems within the scope of this paper. For the purpose of the paper each hazard is discussed separately, although in practice more than one hazard is present in many locations.

As far as possible regulations, standards and codes of practice are discussed in the appropriate sections. There is, however, one general regulation which applies to all locations and which may therefore be cited here. This is Regulation 27 of the Electricity Regulations 1908[2] which reads :—

"All conductors and apparatus exposed to the weather, wet, corrosive, inflammable surroundings or explosive atmosphere or used in connection with any process or for any special purpose other than for lighting or power shall be so constructed or protected, and such special precautions shall be taken as may be necessary to prevent danger in view of such exposure or use."

This regulation covers the *possibility* of danger and not only the actual *presence* of danger; that is, if there is any risk of a hazard occurring from any cause, suitable equipment must be installed[3].

(2) Hazards of Fire and Explosion[4]

Many industrial processes produce or use volatile liquids, vapours, gases, dusts and fibres which, when mixed with air in certain proportions, form inflammable mixtures. These mixtures can be ignited by different sources of which Strachan[5] lists six—flame, electric arc, electric sparks, hot wires (e.g., lamp filaments), hot surfaces and frictional sparks. Lighting fittings and their auxiliaries are thus potential sources of ignition should their design or installation be incorrect, should failure occur or maintenance be faulty.

There are, however, few locations in industry where explosive mixtures are present *all* the time; if they were it would often not be possible for men to work. Consider,

Fig. 4. Doors of intermittent vertical retort showing low contrast between levers and surrounding ironwork.

for example, the danger of explosion with carbon monoxide/air mixtures. These are inflammable if the proportion by volume of carbon monoxide lies within limits of 12.5-74 per cent. But the limiting concentration for carbon monoxide poisoning (for a period of one hour) is 100 parts per 1,000,000, i.e., less than 1/1,000th of the minimum explosive concentration. Consequently any carbon monoxide/air explosion in a plant where men are working can result only from an accident or a plant breakdown. Nevertheless, although the probability of danger may be small, the Electricity Regulation 27 makes it plain that electrical equipment installed in such locations must be able to combat the hazard.

It is convenient to divide the inflammable and explosive media into three groups, namely, (a) vapours and gases, (b) dusts and fibres and (c) explosives.

(2.1) Vapours and Gases

This paper is concerned chiefly with the basic industries—such as the gas, oil and chemical industries—where inflammable liquids, gases and vapours are manufactured and processed, but there are many locations in general industry where these materials are used and where a hazard is created by their use. Among such locations are cellulose spray shops, aeroplane hangars, garages and filling stations, dry cleaning and dyeing factories, linoleum, rubber, paint, paper and soap factories, refrigeration plants and tanneries.

The hazard from inflammable gas or vapour/air mixtures is thus widespread. It is also well recognised and much research has been devoted to its understanding and to developing protective systems.

(2.1.1) *Nature of Hazard: Regulations, Standards and Codes of Practice*

The relative risk and severity of a gas or vapour/air explosion depends on several factors including the characteristics of the gas or vapour, the range of concentrations in air which are inflammable, the intimacy of mixing and the shape and size of building or vessel in which the explosion occurs. The density of the gas can also be important; a heavy gas or vapour may creep over a considerable distance, reach a remote source of ignition and then flash back.

Another hazard is the "cool flame." This is a partial combustion flame which can occur in most hydrocarbon gases, although not in methane and benzene. The limiting mixture concentrations within which cool flames occur depend on the temperature and pressure, the range increasing with increase of temperature and pressure. The limits usually overlap the limits for normal combustion, but with ether at room temperature and atmospheric pressure there is a gap between the two sets of limits. The cool flame is visible only in the dark and may persist for some time before developing into normal "hot flame" combustion. Cool flames are ignited directly only by sources at temperatures between 180 deg. C. and 420 deg. C.

The design of electrical apparatus to operate in inflammable atmospheres has been studied for many years both by the Safety in Mines Research Establishment and by the Electrical Research Association. From this work came first the conception and then the details of design of British "flameproof" equipment[5, 6, 7, 8, 9, 10].

Before 1930 data had been established only for methane/air mixtures. Since then similar data have been obtained for some 30 gases and vapours which are present in industrial plants and processes. Details of the inflammability and explosion characteristics of these gases and vapours are given in Table 1.

Apart from the general requirements of the Electricity Regulation 27, the following regulations contain references to the use of lighting equipment in specific locations: the Cellulose Solutions Regulations (Regulation 5b)[11], the Chemical Works Regulations (Regulation 4b)[12], the Cinematograph Film Regulations (Regulation 12)[13] and the Testing of Aircraft Engines Special Regulations (Regulation 14)[14]. These regulations require that where inflammable liquids are present or where inflammable mixtures of

Table 1

Explosion Characteristics of Inflammable Gases and Vapours

Gas or Vapour	Limits of inflammability (per cent.)	Most incendive mixture		Most easily ignited mixture		Mixture for max. pressure	
		per cent.	mg./litre	per cent.	mg./litre	per cent.	mg./litre
I. Methane	5–15	9		7.5		9.8	
II. Blast furnace gas	28–70	55		55		53.4	
Propane	2–9.5	4		4.3		4.6	
Butane	1.5–8.5	3		3.7		3.6	
Pentane	1.5–7.5	3		3		3	
Hexane	1–7		99		80		86
Heptane	1–6		115		85.5		99
Iso-octane	0.5–3.5		85		68		80
Decane	0.5–2.5		120		105		160
Benzene	2–8	3.5		5		3.9	
Xylene	1–6		107		87		110
Cyclo-hexane	1–8.5		90		80		100
Acetone	3–13	5.5		8		6.3	
Ethylene	2.5–35	6.5		6.5		8	
Methyl-ethylketone	2–12	5		4		4.6	
Methyl acetate	3–15.5		208		152		193
Ethyl acetate	2–11.5		160		180		185
Propyl acetate	1.5–8		135		130		145
Butyl acetate	1.5–15		130		130		150
Amyl acetate	1–		110		150		140
Methyl alcohol	5.5–36.5		197		183		183
Ethyl alcohol	2.5–19		115		135		140
Iso-butyl alcohol	1–50		105		125		123
Butyl alcohol	1–		115		125		160
Amyl alcohol	1–		100		100		151
Ethyl ether	1.5–48	4		3		4.1	
III. Coal gas	5.5–31	18		17		21	
IV. Acetylene	2.5–82	—		—		14.5	
Carbon disulphide	1–50	10		7.5		7	
Hydrogen	4–74	23		—		32.3	

(N.B.—These data are taken from Appendix D of B.S. 229 : 1946 where full details of the conditions of test are given).

gases or vapours with air may occur, all lighting equipment installed *within the danger area* must be of flameproof construction (as defined in B.S. 229 and B.S. 889) and certified for the particular gas or vapour[15, 16, 17]. Codes of practice have been prepared and published by some industries and large companies[18, 19, 20] to supplement the regulations.

Study of Table 1 shows that the scheduled list of gases and vapours is not complete, and this is recognised in the foreword to B.S. 229 which states "It is intended that the list of gases and vapours included in any group shall be added to from time to time, when information becomes available." Where gases other than those of Table 1 are present, one of two actions is recommended in Appendix F of this Standard. If the gas or vapour is one of a chemical series whose extreme members are scheduled, flameproof equipment having the gap dimensions specified for the scheduled members can be installed within the danger area. If, however, the gas does not form part of such a series the lighting fittings must be mounted outside the danger zone. As described in the next section, experiments are being made with pressurised fittings for lighting areas where non-scheduled inflammable gases are present.

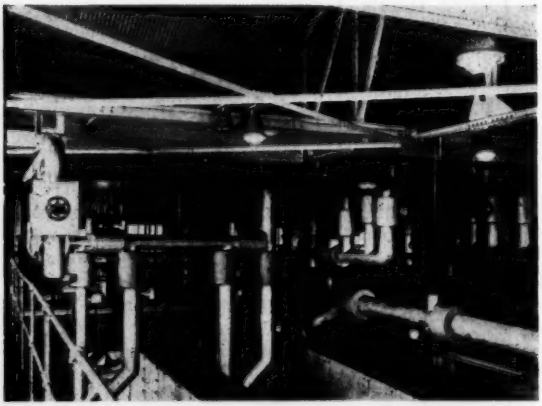


Fig. 5. Filament lamp flameproof fittings in a dewaxing plant.

Fig. 6. 300-watt filament lamp flameproof fittings in a gas exhauster plant; mounting height 19 ft.

(2.1.2) *Methods of Protection: Modern Practice*

Locations where inflammable gas or vapour/air mixtures may be present are usually lighted by certified flameproof fittings mounted within the danger area; the dewaxing plant installation shown in Fig. 5 is typical.

The safety of this form of lighting and its suitability for many locations are beyond question, but it has limitations; some are evident in Fig. 6, which shows flameproof fittings in a gas exhauster plant. The steam-driven pumps pull gas from the retorts and push it through the purification plants. The staff must supervise the running of the machines and regularly check meter and gauge readings. Gas is not normally present in the house, but an accident may occur or gas may leak from a faulty gland or joint, and so 300-watt Group III flameproof well-glass fittings with over-reflectors are used for lighting. The spacing between fittings is as close as reasonable, but with the 17-ft. mounting height necessary in this house the illumination is only about 4 lm/ft^2. The appearance of the house and the working conditions at night are depressing, and the installation must rank as poor by modern standards of industrial lighting. Although the safety standards of British flameproof equipment must be maintained, the difficulty of achieving really good lighting when filament-lamp flameproof fittings are mounted at 15-20 ft. should be recognised. One reason for this is the limited light output of single units. The use of lamps larger than 300 watts is prevented by the difficulty of designing reasonably sized fittings whose surface temperature rise does not exceed 50 deg. C.—the limit specified in B.S. 889. Whether this limit should apply to all gases and vapours has long been a matter of contention; in the authors' opinion the permitted temperature rises might well correspond more closely to the ignition temperatures of the gases or vapours. It is significant that German practice specifies different temperature limits for different groups of gases[21] and that in the United States a surface temperature not exceeding 80 per cent. of the ignition temperature of the gas or vapour is allowed.

Another general criticism of many flameproof fittings is the absence of light control; frequently fittings are no more than housings for unshielded lamps. Although B.S. 889 now permits the use of prismatic or diffusing annealed glasses in fittings which do not have to pass the specified impact test, some engineers prefer the plain toughened glass for arduous service conditions. One answer to this problem is to use a combination cover of an inner toughened glass and an outer acrylic cover, as in the diffusing fitting shown in Fig. 7. The glass forms part of the flameproof enclosure, is strong enough to withstand an internal explosion and shields the acrylic shaping from the hot convected air streams which rise from the lamp. The opal acrylic cover has a luminance of only 2.5 cd/in^2 and with its high impact strength reduces the risk of breakage.

Fluorescent lamp flameproof fittings are not widely used in industrial plants in this country owing mainly to their high cost, considerable weight and small light output. The heavy weight of all flameproof fittings is often a problem to engineers. Should the use of aluminium alloys be prohibited because of the danger of incendive sparks when castings are struck a blow, difficulties of installation and maintenance will be gravely increased.

Against this background it is not difficult to understand why the trends of modern practice are to combat the hazards of fire and explosion by means other than the use of flameproof fittings.

In some locations engineers are using pressurised systems in which entry of the inflammable vapour is prevented by maintaining a positive pressure within the system[22]. For lighting a paraxylene compressor house in a chemical works, ducts were built into the flat roof of the house and industrial dispersive fittings mounted in them. The ducts are closed at the bottom by toughened glass plates and at the top by covers which project above the roof and can be removed for servicing. There

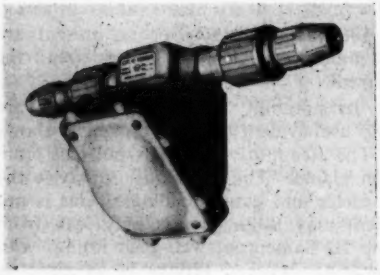


Fig. 7 (above). 60-watt filament lamp flame-proof fitting with toughened glass inner cover and opal acrylic outer cover.

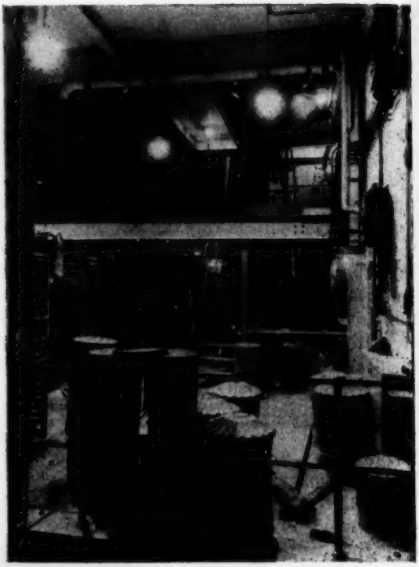


Fig. 8 (right). Installation of pressurised fittings lighting location where Group IV gas is present.

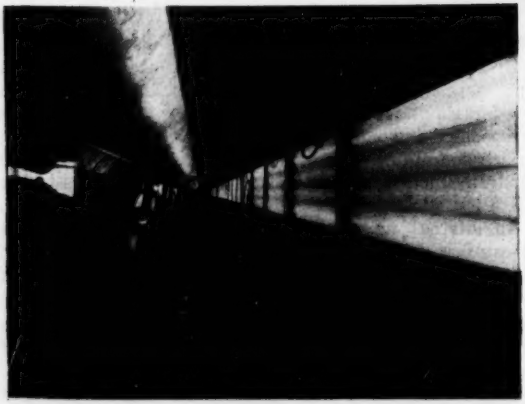


Fig. 9. Paint spraying line in car factory lighted by projection through sealed glass wall panels.

is easy access to the fittings. The complete system is pressurised by air to a few inches of water; a pressure switch at one end of each line controls a contactor.

A pressurised system is also used for lighting the olefine plant at the same works, but here the roof is not suitable for a built-in system. A walkway running down the centre of the building above the crane supports the centre row of fittings which are housed in steel boxes and can be serviced from either the top or side. Two other rows of fittings are supported on small branches off the main walkway.

By special arrangement with the Chief Inspector of Factories, pressurised systems have been installed in locations where one of the "excluded" gases of Group IV is present (Fig. 8). In these systems individual fittings are pressurised, the air

supply to them being either through the conduit or through an independent piping system feeding into the fittings; the latter method is usually preferred. With well-constructed fittings the rate of air leakage from such systems is quite low, as shown by Holmes in recently reported experiments[23].

It is sometimes difficult with pressurised systems to avoid corrosion caused by contamination of the air supply. In one plant corrosion was avoided by using nitrogen from one of the works' processes.

Another method of protection against gas and vapour hazards is to isolate the fittings from the danger area. Fittings are mounted outside fixed and sealed roof-lights or windows and light inwards (Fig. 9), non-flameproof fittings may then be used.

Where exterior lighting systems cannot be used, the number of flameproof fittings can often be reduced by restricting the danger area itself. This is now customary practice in gas-pumping houses, for example. If the boosters are isolated from the electric motors by a dividing wall and driven through wall boxes of the gland type, flameproof equipment can be limited to the area of the booster house; in the motor-house non-flameproof fittings and equipment can be used. All doors in the danger section of the building must open to the outside air, otherwise gas liberated by a plant failure may creep through the connecting passages into the presumed safe zones of the building and there be ignited.

Alterations in plant or building design can sometimes effectively reduce the danger; this is illustrated by the two gas purification plants shown in Figs. 10 and 11. In both

Fig. 10. Gas purification plant—old building.

Fig. 11. Gas purification plant—new building.

plants elevated purifiers are used, and to change the iron oxide men enter the tanks at the top and dig through the oxide which is then discharged through the bottom doors. When a tank is opened, which only occurs every 2-3 weeks, gas is released. As the ventilation on the older plant (Fig. 10) is bad owing to the building construction, flame-proof fittings are necessary here. In the new plant shown in Fig. 11, however, ventilation is good and fittings are mounted 23 ft. above the floor. The possibility of a dangerous gas concentration near the fittings is negligible and the Inspector of Electrical Factories agreed that flameproof equipment need not be installed; sodium lamp fittings with machined joints are used, the spacing being 30 ft. x 34 ft. The illumination is approximately 7 lm/ft^2 and is adequate for the tasks.

The logical end of these developments is to design plants for largely automatic operation and to build them outdoors. Outdoor and semi-outdoor plants have been common in the oil industry for many years and this practice is extending to other industries. The construction of the first semi-outdoor power station in Great Britain was described in a recent paper[24] and many outdoor chemical plants have been built. In these chemical plants banks of pneumatic controllers hold flows, temperatures, pressures and other operational quantities at values set by the operator in the control

Fig. 12, General view of outdoor section of vinyl chloride plant illuminated by floodlights.

Fig. 13. Mounting floodlights on tower for illumination of vinyl chloride plant.

room. Lighting on the plant itself is consequently mainly for maintenance, inspection and movement. Fig. 12 shows the outdoor section of a vinyl chloride plant which is lighted from outside the danger area by a cluster of 500-watt floodlights mounted on a 30-ft. high tower (Fig. 13). All electric plant is earthed by lead-covered copper wire independently of the cable sheathing which is also earthed, and all controls are located in a safe area.

(2.2) Dusts and Fibres

(2.2.1) *Nature of Hazard: Regulations, Standards and Codes of Practice*

In 1911 two serious explosions were caused by the ignition of dust suspensions in the atmosphere, and the Factory Department at once sponsored research into the inflammability of all carbonaceous dusts then known to be present in industrial processes. The work was directed by the late Professor R. V. Wheeler, who concluded [25] that any dust could be placed in one of three categories:—

Class 1: Dusts which ignite and propagate flame readily, the source of heat required being comparatively small, e.g., an electric spark or an exposed incandescent filament.

Class 2: Dusts which are readily ignited but which, for the propagation of flame, require a source of heat (a) of large size and high temperature, such as an electric arc, or (b) of long duration.

Class 3: Dusts which do not appear to be capable of propagating flame under any conditions likely to occur in a factory,

(a) because they do not readily form a cloud in air,

(b) because they are contaminated with a large quantity of incombustible material, or

(c) because the materials of which they are composed do not burn sufficiently rapidly to produce enough gas.

Arbitrary as Wheeler's tests were, they laid the foundation for later investigations such as those of Brown, who in his report[26] asks three questions—Will the dust in the form of a cloud ignite and propagate flame? At what density is the cloud explosive? What is the pressure developed by the explosion?

The explosion danger of any dust depends, among other things, on the physical character of the dust, the particle size distribution, the dispersion and the concentration.

As with gases and vapours, experiments have shown that there is a range of concentrations of any given dust which will propagate flame. Wheeler later investigated the risk of explosions in grain silos[27] and found that rice meal dust was inflammable in concentrations varying from 0.05 oz./cu. ft. to 1.43 oz./cu. ft. (i.e. a range of 30 : 1); the maximum velocity of flame propagation occurred when the concentration was 0.45 oz./cu. ft. The minimum concentration for inflammability of many dusts is about 0.03 oz./cu. ft.

In addition to the concentration of the dust the particle size distribution has an important influence on inflammability. For example, large particles can act as a diluent and can also affect the ability of the dust to form a cloud in air.

The pressure developed in dust explosions depends largely on the size of the vessel or room in which the explosion occurs and on the means of pressure relief. Wheeler's experiments on grain silos were made in a steel cylinder 30 ft. high and 7½ ft. diameter. When 1/9th of the top was open the pressure developed with a particular grain dust was 17 p.s.i.; with the top two-thirds open, however, this explosion pressure was reduced to 0.5 p.s.i.

Wheeler listed 60 dusts in Class 1 but later investigations have added to the number, and in the latest Factory Department Memorandum[28] more than 150 dusts are in this category. Among them are a number of metal dusts, including those of

aluminium, magnesium and zinc. It is interesting that the concentrations of these metallic dusts found to be explosive are similar to those of the carbonaceous dusts.

In the United States National Electrical Code[29] fibres are classed separately from general dusts. It is American experience that thin films of fibres on equipment and machinery are easily ignited, resulting in a flame which travels with almost explosive velocity; very serious accidents from this cause have occurred.

The only general regulation having specific reference to dust hazards is that included in Section 28 of the Factories Act 1937, which requires that certain precautions be taken where there is present ". . . dust of such a character and to such an extent as to be liable to explode on ignition," and additional precautions are necessary ". . . unless the plant is so constructed as to withstand the pressure likely to be produced by any such explosion." As far as individual industries are concerned, Regulation 13 of the Magnesium (Grinding and Polishing) Regulations[30] states ". . . no open light . . . or other agency capable of igniting dust of magnesium shall be permitted at any place less than 20 ft. from any of the following . . ." which might be interpreted as requiring special design for any lighting fitting mounted within 20 ft. of the places described.

Although some guidance is given in a Home Office Memorandum[31] on the design of fittings which have to operate in hazardous dusty atmospheres, no British Standard has been prepared. Some consequences of this will be apparent in the following Section.

(2.2.2) *Methods of Protection: Modern Practice*

Three methods of combating fire and explosion hazards from dusts are possible: dust-tight equipment mounted within the danger area can be used, ordinary fittings can be mounted outside the danger area, or the plant can be designed to eliminate—or reduce to a safe limit—the quantity of free dust in the atmosphere.

The difficulty facing engineers who wish to mount fittings within the danger area has been indicated: in the absence of a British Standard formulating tests for dust-tight equipment there is no standard of performance by which fittings can be judged. Some of the fittings described as "dust-proof" are ineffective in service. Fittings so described were installed in the coal-handling area of one boiler plant, and within a week their interior surfaces were lined with coal dust. The need for developing suitable tests and preparing a standard for dust-tight equipment is urgent. Effective dust-tight fittings have been produced—often to the special requirements of plant engineers—and the knowledge gained can be used. One fitting of proved

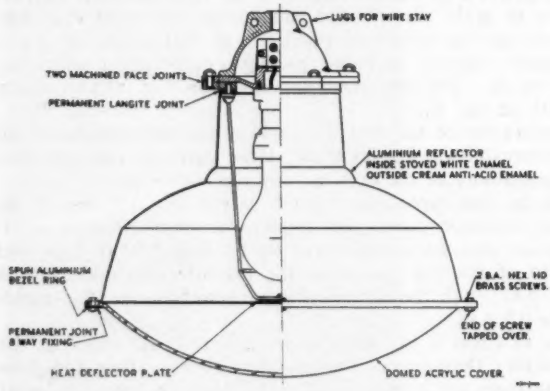


Fig. 14. Dust-tight dispersive reflector fitting for filament lamps.

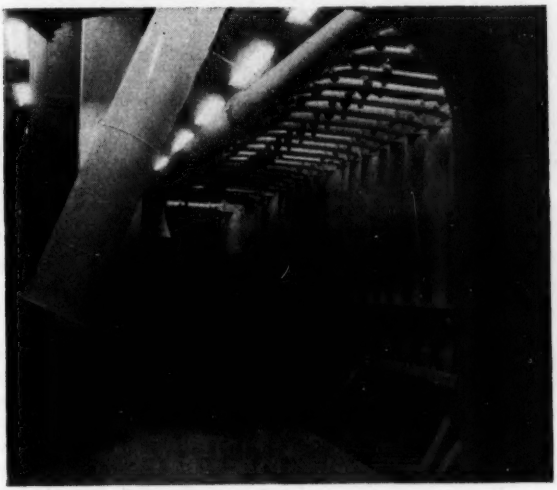


Fig. 15. Junction of pipe transporter system on top floor of flour mill.

performance is shown in Fig. 14; this is an industrial dispersive unit of the overlamp type. The acrylic front cover is sealed to the aluminium reflector by a plastic cement applied between the reflector flange and the aluminium bezel ring; the assembly is then bolted together with eight-way screws so making a permanent joint. To replace the lamp or service the fitting, the machined joint at the top is broken by removing the studs. Before re-assembly the machined faces are greased. Machined face joints are probably the most satisfactory for dust-tight equipment, but they are expensive and it should be possible to use properly designed gasket joints. The memorandum mentioned earlier permits the use of gaskets if they are non-perishable; it does not, however, indicate what materials satisfy this requirement. The development of silicone-rubbers[32, 33, 34] may provide the practical answer to this official demand. These materials are unaffected by light, they can be moulded and extruded and they can operate at temperatures of 150-180 deg. C. without losing the resiliency essential in any effective gasket. Comparable properties are claimed for the fluorocarbon rubbers now being made on a small scale in the United States.

Fittings should have contours which prevent dust settling so thickly that the surface temperature rises to values at which organic dusts char and ignite. Smooth contours free from ledges are essential and German practice suggests that the angle to the horizontal of the main section of the body should be at least 60 deg. In the United States a limiting surface temperature of 165 deg. C.—and in Germany 120 deg. C.—is specified for all fittings installed in locations made hazardous by the presence of combustible dusts.

Performance tests on dust-tight fittings might well make use of Holmes's idea of a maximum rate of air leakage from the fitting when pressurised to a few inches of water. Tests similar to those specified for dust respirators might also prove useful.

In the second method of protection against dust hazards—mounting fittings outside the danger area and lighting by projection—the plant engineer is faced with the problem of high light absorption by dusty atmospheres. Measurements made in a steel works showed absorption losses of approximately 50 per cent. in a distance of 50 ft.[35]. Even so, this is sometimes the only method open to engineers and normal practice is to

light by projection through sealed windows; fittings having a concentrating distribution should be used where possible.

In some industries hazards of dust explosions have been overcome by designing plant so that the dust does not escape into the atmosphere in sufficient amounts to form an inflammable mixture. Flour is among the Class 1 dusts and in modern mills all plant is enclosed[36]. Grain and flour are conveyed in aluminium alloy pipes between machines, combined gravity and pneumatic feed being used; the pipes have observation windows where necessary. Fig. 15 shows the upper junction of the piping system on the top floor of a modern mill; fluorescent lamp reflector fittings of normal design are used for lighting. The grinding rolls and other machines are lighted by similar fittings positioned to enable the process to be observed through glass windows in the machine covers. Experiments were made some years ago of lighting machines by filament lamps enclosed inside the covers. It was found, however, that the heat from the lamps could char the flour deposits which formed on the lamp enclosures and this method of lighting was abandoned.

The danger of using non-approved lighting equipment for maintenance operations on plants where vapour or dust hazards are present[37, 38] is sometimes overlooked; it can be illustrated by an accident that occurred in a paper mill. Paper dust was exhausted into a dust chamber which it was usual to clear at week-ends. Approved portable lighting equipment was not used and on one occasion failure occurred causing sparking which ignited the dust; two workmen were killed by the explosion.

It was surprising to learn how the dust deposits are cleaned from the walls of grain silos at one British port. A chain is swung to sweep the walls and the progress of the operation is checked from time to time by lowering an ordinary handlamp into the silo and viewing from the top platform. While it is true that no accident has occurred in this country over many years, a serious explosion in a Canadian grain silo has been reported.

(2.3) Explosives

(2.3.1) *Nature of Hazard: Regulations, Standards and Codes of Practice*

The danger in explosives plants is always potentially greater than in other hazardous locations owing to the properties of the explosive materials. Some, such as lead azide, are extremely sensitive and minute amounts of energy can cause an explosion. Explosive materials provide their own oxygen for combustion and the explosion velocity may vary widely according to the type of material and the conditions. For example, black powder—a non-detonating propellent—has an explosion velocity of 900 ft./sec., while T.N.T.—a high explosive—has a velocity of 22,000 ft./sec.

The installation of lighting and electrical equipment in plants manufacturing and storing explosives is controlled by a number of Regulations and Codes of Practice including the Factory Acts of 1937 and 1948, the Explosives Act of 1875, the Explosives Substances Act of 1923 and the Electricity Regulations of 1908. The Home Office Memorandum on Electric Light and Power in Explosives Factories gives general guidance on installation practice and this is supplemented by publications prepared by manufacturers.

(2.3.2) *Methods of Protection: Modern Practice*[39]

Unlike most industrial plants, the danger areas in an explosives factory cover most of the site and precautions are necessary to prevent an explosion in one area being relayed to adjacent areas. For this reason "danger" buildings are usually small in size and isolated from each other by surrounding earthen mounds. The form of lighting permitted in any building depends on the process and its associated hazard.

Some buildings may be lighted only by either (a) Wall-mounted flameproof fittings so installed that only the wall-plate and glasses are within the building, the fittings

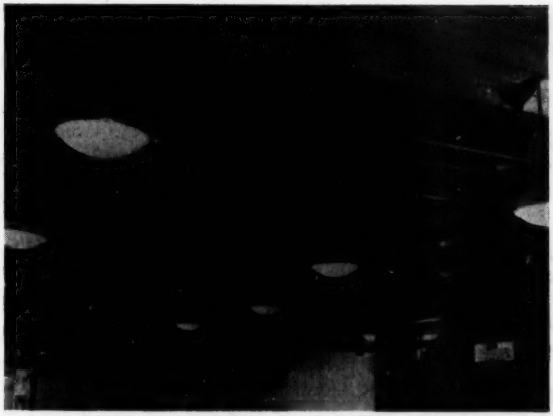


Fig. 16. Installation of dust-tight filament lamp fittings in cartridge filling plant of an explosives factory.

being serviced from outside, or (b) Fittings mounted outside the building lighting through fixed windows or roof-lights.

The nitrating building in a particular nitro-glycerine plant is typical of these locations. The nitrator and separator are mounted on a platform about 20 ft. above the floor and higher than the mound surrounding the building. The operator has to observe the mixing of liquids in the nitrator through a glass top-plate and to read a thermometer which passes through this plate. Owing to the building construction it was not possible to light through the roof, and for many years wall-mounted flameproof fittings were used which gave an illumination of less than 1 lm/ft^2 on the top plate of the nitrator. The general conditions in the plant are unpleasant and this inadequate illumination increased the strain on the operators. The problem has now been solved by mounting two flameproof flood-lights on the surrounding mound and training their beams on to ceiling-mounted, stainless steel plates from which the light is reflected to the nitrator; the resulting illumination is about 20 lm/ft^2. The system is expensive but the cost is justified by the location, the task and the working conditions.

In buildings where some other explosives are handled, pendant flameproof fittings can be used but they must be correctly suspended. Experience has shown that when an explosion occurs in one building, the resulting shock waves through the air can cause fittings in adjacent buildings to "bounce." If these fittings are heavy—as flameproof fittings are—and are suspended by conduit only, this "bounce" may strip the conduit thread with the result that the fittings fall and snap the wiring. To guard against this all pendant fittings must have safety suspension wires.

In flameproof installations, wiring is usually in solid drawn conduit and the malleable iron junction boxes used are filled with sealing compound. Double-pole switchgear is always used and is mounted outside the building. If the danger is particularly great the switchgear is located outside the mound.

Where the hazard is caused by the presence of some explosive dusts the use of pendant dust-tight fittings of approved design is permitted. The cartridge filling plant shown in Fig. 16 was originally lighted by wall-mounted flameproof fittings but, except in the vicinity of individual fittings, the illumination was very low. Specially approved lightweight dust-tight fittings have now been installed as shown in the photograph. The average maintained illumination is 7 lm/ft^2, which is sufficient for this type of work.

All electrical equipment in an explosives plant must be regularly serviced. In one plant the service schedule requires equipment to be dismantled and inspected not less often than once in six months. Fittings are carefully cleaned, any machined faces greased and the gap dimensions in flameproof equipment checked after reassembly.

Insulation and earth continuity tests are made and after re-erection the installation is painted.

The explosives industry illustrates well how the lighting of very hazardous locations can be improved, without impairing safety, by studying the nature of the hazard. Less than 20 years ago the artificial lighting in most explosives danger buildings was primitive; to-day it is generally adequate to the visual task, even where this is exacting as it is in fuse assembly.

(3) Hazards of Chemical Attack

The hazards of fire and explosion are caused, in part, by installing lighting fittings in certain locations, i.e., the equipment is one *source* of the hazard. In locations where chemical attack is likely the reverse is true, the equipment being *subject* to the hazard.

Moreover, the nature and the result of the hazard are different. Chemical attack affects the performance and reliability of the equipment and increases maintenance and replacement costs, but it rarely endangers life and plant.

Perhaps this is part of the reason why the seriousness of this hazard is not generally appreciated. Some years before the war Hadfield estimated the world cost of metallic corrosion to be at least £700 million a year, and in a recent paper Forrest and Ward[40] showed that the life of S.C.A. overhead line conductors was reduced by corrosion from about 50 years in rural areas to 10 years or less in heavily industrialised districts. The same problem is a constant concern to the engineers of many industrial plants[41].

(3.1) Nature of Hazard

Although metallic corrosion is the most serious form of chemical attack, some of the plastics now used in lighting fittings are also attacked by certain chemicals. As the two types of attack and their results are different, it is convenient to consider them separately.

(3.1.1) *Corrosion of Metals*[42, 43]

Evans has defined corrosion as "the destruction of metals by chemical or electrochemical agencies," and in his classical work on the subject lists 10 causes of corrosion currents :—

(i) Differential aeration;
(ii) Contact with other metals;
(iii) Presence of impurities;
(iv) Grain boundaries;
(v) Differential thermal treatment;
(vi) Local scratches and cut edges;
(vii) Differential stress or strain;
(viii) Differential concentration of salts;
(ix) Differential heating;
(x) Differential illumination.

It is only necessary here to comment in general terms on the more important of these causes.

Some metals—iron is typical—when exposed to the atmosphere combine with oxygen and an oxide film is formed over the surface of the metal. If, however, this oxide film is not complete—or is broken—and the surface becomes covered with a salt solution (e.g., by deposition from some process), the oxide layer will act as cathode and the metal as anode. A current will then flow from the cathode to the anode resulting in attack over the anodic area. The larger the ratio of the cathodic to the anodic area the more intense will be this attack.

Electrochemical action also occurs where different metals are in contact in the presence of a salt solution; the attack is again on the anodic member of the couple. The intensity of the attack depends on the relative position of the two metals in the Potential Series; the greater the difference between the potentials the greater will be the corrosion current.

Corrosion sometimes occurs when the contact area between a metal and a non-metal—such as glass or porcelain—is wetted. The reason may be that the oxygen in

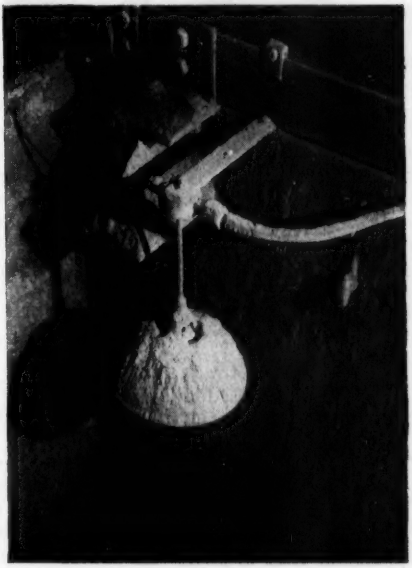


Fig. 17. Dust deposit on a lighting fitting mounted in a sulphuric acid plant.

the solution within the "crevice" between metal and non-metal is replaced more slowly than it is elsewhere. This would cause the metal in the crevice to become anodic relative to that outside, and attack would then occur at the interface.

Serious corrosion can occur at the grain boundaries in metals; the probability and severity of attack depend on the metal structure and on the presence of stress. If the metal is not stressed attack may start at the grain boundaries, but it is quickly stifled and then spreads more or less uniformly over the surface. When, however, the metal is stressed by an applied load, the crevices between the grains may be opened and intergranular attack may be serious. Experiments have shown that when metals are subjected to an alternating stress in a corrosive atmosphere their fatigue strength can fall.

The rate of any type of corrosion depends on several factors. Fundamental among them are the nature of the metal and the corrosive agent; others include the solubility of the corrosion product and—where attack is uniform—the nature and permeability of any film which is formed over the surface. If the corrosion product is hygroscopic it may absorb moisture continuously above a certain critical humidity, resulting in a greatly increased rate of attack. The settling of some dusts on metal surfaces can have a similar effect (Fig. 17).

The effect of heat on corrosion rates is not easy to decide. In general heat accelerates chemical reactions, but in corrosion it may reduce the rate by driving moisture from the corrosion product.

Where the corrosive is an acid or alkali the development and nature of the protective film formed may be important in determining that rate of attack on some metals. For example, if the corrosive is sulphuric acid the addition of molybdenum to austenitic stainless steels improves their behaviour by improving the acid resistance of the film formed.

The above discussion has been concerned only with natural corrosion in which there is no applied e.m.f., but engineers have reported trouble from the corrosion of conduit and cable sheaths caused by stray currents near D.C. power systems.

Fig. 18. Start of corrosion on lighting fitting in a sulphuric acid plant.

(3.1.2) *Chemical Attack on Non-Metals* . .

The glasses used in lighting fittings are immune to chemical attack but the ethenoid plastics, while resistant to most inorganic corrosives, are attacked by some organic chemicals.

Solvent attack on acrylic and other plastics may produce the fine but sometimes deep cracks known as "crazing," which cause a considerable fall in mechanical strength[44, 45]. This danger is increased if the component is badly fabricated or stressed in service. Recent experiments have shown that certain plasticizers, including di-butyl phthalate, used in p.v.c. wire and cable insulation are among the materials which can cause this crazing. This arises from their nature as partial solvents, and the higher their volatility the greater is the risk of crazing. Satisfactory formulations are available and should be specified for wire used in acrylic fittings. Although the susceptibility of plastic components to crazing can sometimes be reduced by annealing, there is no complete protection against this form of chemical attack. If it is likely to occur owing to the presence of solvents, ethenoid plastic components must not be used.

(3.2) Principles of Protection

Chemical attack is so varied that it is unwise to be dogmatic about methods of protection, but in general there are four lines of defence against natural corrosion:—

(i) Choice of materials;
(ii) Protective finishes;
(iii) Design details;
(iv) Maintenance in service.

(i) Most engineers consider that sheet metal fittings are rarely satisfactory in highly corrosive locations whatever finishing treatments are used, and where possible cast components are specified. The light weight of aluminium alloys is an advantage and fortunately a number have very good resistance to corrosion[46, 47, 48]. Other necessary properties, such as casting characteristics, have to be remembered when selecting an alloy; the 10-13 per cent. silicon-aluminium alloys, such as LM6 and LM9, have very good properties and are widely used.

Most corrosion problems in service are associated not with the main casting of the fitting but with auxiliary components such as glands and fixing studs, and for these the correct choice of material is most important. Copper-containing metals should never be used in contact with aluminium alloys; galvanised or plated steel components are sometimes chosen but these also are seldom satisfactory. It is difficult to produce a galvanised or plated coating wholly free from pores, and even if this is achieved the coating will probably be broken by abrasion during erection or servicing. While it is true that the correct plating metal can "sacrificially" protect the base, the period of effective protection is limited. It is better to choose a corrosion resistant

metal, and for use in silicon-aluminium alloy castings one of the best materials is 18:8 chromium-nickel austenitic stainless steel.

There remains the choice of material for the light controlling component. In the authors' opinion, glass or acrylic refractors are preferable to specular reflectors as their optical efficiency will rarely be degraded by chemical attack.

There is no entirely satisfactory specular reflecting material. Lead-backed silvered glass reflectors probably have the best corrosion resistance, but they are fragile and not easy to mount. Electrolytically brightened and anodised aluminium reflectors have the necessary mechanical properties, but researches by one of the authors and his colleagues some years ago showed that when the surfaces were wetted breakdown of the anodic film occurred sooner or later(49). When anodised aluminium reflectors are used the anodic process should conform to B.S. 1615(50) as the nature, thickness and sealing of the film largely determine its resistance to chemical attack. Other metals, including polished stainless steels, have been used for specular reflectors but suffer from the disadvantage of comparatively low reflection factor.

With diffuse reflectors the problem is somewhat easier. It is true that in highly corrosive locations both stove and vitreous enamelled steel reflectors have a very limited life—owing mainly to the difficulties of completely covering the edges and of chipping in service (Fig. 18)—but opal acrylic(51) and unplasticised p.v.c.(52) reflectors are now available for both fluorescent and filament lamp fittings and these materials can withstand attack by most inorganic corrosives.

(ii) During the last 10-15 years many finishing processes have been developed for protecting metals against corrosion and the problem of the fitting manufacturer is to choose between them(53). It is only possible in this paper to describe two methods of protection.

The first is a paint process. Until recently the finishing system recommended by one paint manufacturer depended on whether the equipment had to resist acid or alkali attack. These alternative systems have now been replaced by a single system using paints based on epoxide resins. The alloy is first treated by a suitable chemical chromating process; an epoxide primer containing red lead is then applied and this is followed by a top coating of an epoxide enamel which is stoved.

However well fittings and equipment are finished it is unlikely that they will be erected without damaging the paint and exposing the metal. For maximum corrosion resistance the equipment should therefore be painted after erection; cold-setting epoxide paints, chlorinated rubber paints and bitumastic paints are suitable.

A less orthodox process is that of flame-spraying coatings of polythene on the surfaces to be protected(54). The coating can only withstand temperatures of 70-80 deg. C. and the process is fairly expensive, but the resistance of polythene-coated equipment to chemical attack is exceptionally good provided that the coating is not porous.

(iii) Corrosion may be reduced by good detail design. This includes the incorporation of lips to shed water or corrosive solutions away from joints, the elimination of crevices and ledges where corrosives may be deposited and trapped, the positioning of fixing bolts and studs on under-surfaces and the shrouding of hinges and clips where these must be used(55).

With the introduction of new and effective adhesives, such as the epoxide adhesives(56), it should be possible to eliminate some of the screws and other fixing devices now used in lighting fittings and which frequently are starting points of corrosion.

This discussion of protective principles has so far been concerned with improving the performance of fittings of conventional design, but a more radical approach is possible.

Most trouble is experienced in locations where inorganic acids or alkalis are present, and here it is possible to take advantage of the chemical resistance of some

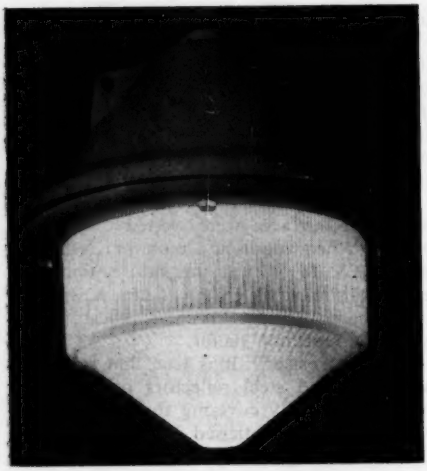
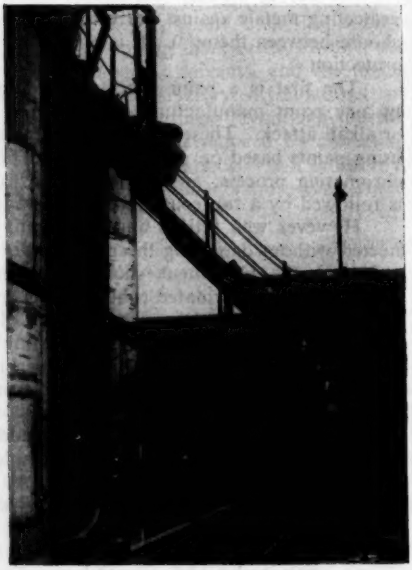


Fig. 19. Corrosion resistant fitting for 200-watt filament lamps.

Fig. 20. (below left.) Corrosion resistant fittings lighting an elevated walkway on a nitric acid plant.

Fig. 21 (below right). Corrosion resistant fittings lighting stair landing and tower floor of nitric acid plant.



of the synthetic plastics by enclosing the lamp and auxiliary gear in a fitting having no exposed metal parts.

By such means it is possible to prevent attack on the outside surface of the fitting, at least for certain groups of corrosives; it remains to prevent the fitting "breathing" which may eventually lead to attack on metal surfaces inside the unit. As with dust-tight equipment two methods of doing this are possible. The first is to seal the fitting; the second to pressurise it. It is difficult to design fittings which are not only

vapour-tight when made but remain vapour-tight over long life in spite of being opened from time to time for lamp replacement. Most gasket materials now in use deform after a time and it may be necessary to treat them as replaceable items, although experiments with silicone-rubber gaskets should be made.

Work has been done on the use of pressurised systems in the highly corrosive atmosphere of dye-houses, but some problems have not yet been solved. Nevertheless the potentialities of these systems for use where corrosives are present throughout a building are considerable.

(iv) The performance over many years of a lighting installation in an atmosphere polluted by corrosives can be greatly affected by the standard of maintenance. All paint films have a limited life, and even in clean atmospheres it is unrealistic to expect an *average* life for the best paints longer than three-five years; in corrosive atmospheres this period may be reduced to 6-12 months. Periodical maintenance painting is therefore essential. The application of grease to metal surfaces, and particularly to moving surfaces such as hinges, can greatly increase the useful life; the high temperatures common in lighting fittings may require the use of silicone greases for this purpose.

It is surprising that lighting fittings are sometimes mounted in positions which make servicing difficult if not impossible. Easy access is essential for good maintenance. When lighting schemes are planned it is more important that fittings should be located where they can be reached than that the layout should be symmetrical.

(3.3) Modern Practice

The many corrosives and the varied conditions in industrial plants make it difficult to select examples of modern practice, but those which follow are reasonably representative.

The first example is the nitric acid plant shown in Fig. 1. As this is an outdoor plant the concentration of acid vapour in the surrounding atmosphere is less than it would be in an indoor plant, but on the other hand fittings are not only liable to attack by this particular corrosive but by other chemicals manufactured on the site. The fittings are also exposed to the weather.

At first porcelain well-glass fittings with vitreous enamelled reflectors were used on this plant but service experience showed two defects: few of the enamel coatings were complete so that attack was rapid, requiring replacement of the reflectors at six to nine month intervals, and the well-glasses seized in the porcelain holders. These fittings are now being replaced by the fitting shown in Fig. 19. Light control is by a glass refractor system consisting of an interior dome and an enclosing bowl. The bowl is carried in an LM6 cast ring fixed by four stainless steel studs to the head of the fitting, which is also cast in LM6 alloy. A rubber gasket seals the fitting and the head has a lip to shed water away from the joint; suspension holes for safety wires are provided. The castings are first treated by a chromating process, then sprayed with a red oxide/chromate primer which is stoved, and finally finished by spraying and stoving an alkyd resin paint top coat. Figs. 20 and 21 show fittings in position on the plant. As far as possible fittings are supported from steel standards so located that the fittings can be serviced without erecting special staging. Some of the fittings have been operating for 18 months and a recent inspection showed that apart from the paint, which is now failing, they are in very good condition. This fitting was developed by the manufacturer in collaboration with the user, and its success in overcoming the corrosion hazard on this plant can be attributed in no small measure to this collaboration.

On any plant not only the fittings but the whole installation must be corrosion resistant. The engineers responsible for electrical equipment on the site of this particular chemical works are now installing for all wiring two, three and four-core armoured cables sheathed overall with p.v.c. and made to their own specification. The

radial thickness of the sheathing varies from 0.06-0.10 in. depending on the cable size. The cable is brought into a special mild steel gland screwed into the head of the fitting, the junction and gland being wrapped with an impregnated tape. To prevent damage to the p.v.c. sheaths, the cable runs are supported by p.v.c. tapes reinforced with wires.

Fluorescent lighting is not usually suitable for outdoor plants but indoors it can frequently be used to advantage. Except where flameproof equipment is necessary, fluorescent lighting is used extensively in the dye houses of a large dye works where corrosion is very severe. In one house where phosphorous trichloride and hydrochloric

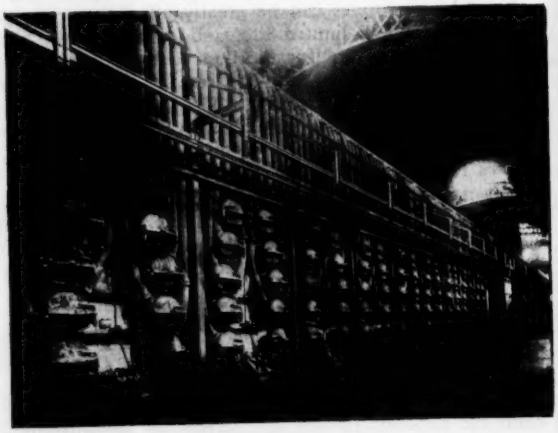


Fig. 22. Gas works' horizontal retort house.

Fig. 23. Gas works' horizontal retort house showing coke being discharged from retorts.

Fig. 24. Vertical retort house in modern gas works.

acid are the predominant corrosives, all metal work is heavily attacked and enamelled steel reflectors have a life of only a few months. Simple fittings designed by the works' engineers were installed some years ago and have given reasonably satisfactory service. Opal acrylic reflectors are used and the lamp caps and holders are shrouded in neoprene mouldings. The starting gear enclosure and the steam pipe used in place of conduit for carrying the wiring are wrapped with an impregnated tape and painted. Even this system has its limitations however. Where fittings are mounted near filter presses they are splashed with dye from time to time, and it has been found that over two to three years some dyes are absorbed by the acrylic reflectors. The resulting discoloration can only be removed by polishing with an abrasive. P.V.C. reflectors are also stained.

Heavy corrosion is reported from some overseas cotton mills in which, during the dry season, the air is humidified by injecting low pressure steam into the building at ceiling level. The cotton "fly" which settles on the fittings is thus kept damp and the corrosion of enamelled steel fittings is very heavy. Here, however, solution of the problem is not difficult as the fittings are attacked on the upper surfaces on which the "fly" settles, and all that is necessary is to provide reflectors and gear covers in a resistant material. Experiments made over a period of 12 months indicate that unplasticised p.v.c. should be satisfactory.

Few locations known to the authors have worse corrosion problems than the gas works' horizontal retort house shown in Figs. 22 and 23. The retorts are charged on one side of the house and discharged on the other by pusher machines. The retort house men have to open, close and lock the doors which are heavily coated with dirt—as indeed are most surfaces in the house; heat and glare during discharging are intense. The red-hot coke is pushed on to a conveyor passing in front of the retorts and quenched by water sprays. Clouds of sulphurous fumes, dust and steam fill the house and, being exhausted through the roof, pass constantly round the fittings. Some of the retort houses in this particular plant are still lighted by gas lamps mounted above the gangway in front of the retorts, but these are being replaced by 85-watt sodium lamp floods mounted on the back wall of the house 20 ft. from the retort faces and 25-30 ft. above the floor. Enclosed fittings with cast aluminium alloy bodies and machined joints are used. Illumination at the vertical retort faces is approximately 6 lm/ft^2. Wiring throughout the house is by armoured cable.

Little can be done in locations such as this to mitigate the corrosion hazard but

notable advances have been made by new designs of retort house plant. Comparison of Fig. 22 with the modern vertical retort house shown in Fig. 24 illustrates how great this advance has been. In the new house the coking process is continuous and most of the plant is enclosed, giving very good working conditions and enabling fluorescent lamp industrial fittings to be used for lighting without danger of corrosion. Such major improvements come only by recognising the dominant part played by plant design in relation to working conditions, and by regarding both the natural and artificial lighting as integral parts of the plant design.

(4) Recommendations

In addition to such major problems as that of plant design, there are several specific problems whose solution could lead to more effective lighting of hazardous locations and it is recommended that the following should be investigated :—

(i) The safe temperature rise of fittings used in locations where Group II and III gases and vapours are present;

(ii) The resistance to crazing of acrylic and other ethenoid plastics in the presence of Group II gases and vapours;

(iii) The effectiveness of pressurised systems for lighting hazardous locations particularly where Group IV and non-scheduled gases and vapours are present;

(iv) The design of, and tests for, dust-tight fittings, preparatory to the issue of a British Standard for dust-tight equipment;

(v) The chemical resistance of various finishes for fittings used in corrosive industrial atmospheres;

(vi) The properties of various gasket materials for use in dust-tight and vapour-tight fittings; the comparison of gasket joints with machined joints;

(vii) The use of epoxide cements for fitting assembly and their behaviour at high temperatures.

(5) Conclusions

The outstanding feature of present British practice in lighting hazardous locations is the recognition of the part played by plant design in combating the hazards. Outdoor plants whose processes are automatically controlled—often from a central control room—are changing the function of artificial lighting and in many ways are easing the problem. These developments are still in an early stage and with the increasing use of electronic controllers automatic operation will be applied to processes in more industries.

Nonetheless, there will remain many locations where special lighting equipment will be needed and there is scope here for development. This depends largely on co-operation between plant engineers, lighting engineers and representatives of Government departments. The formation of the N.I.C. Sub-Committee has provided opportunity for the interchange of information, and advances in lighting equipment and techniques should result.

It is only by comparing modern standards with those of 15 or 20 years ago that the notable progress made in this field of lighting practice can be appreciated. With improved co-operation progress in the future should be as great and more rapid.

Acknowledgments

The indebtedness of the authors to many of their colleagues and to members of the N.I.C. Sub-Committee on Lighting of Hazardous and Corrosive Locations are apparent throughout the paper. They also acknowledge permission to reproduce photographs from the North Thames Gas Board, Imperial Chemical Industries Limited, General Electric Company Limited, Holophane Limited and Hovis Limited.

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Discussion

MR. F. H. MANN (H.M. Senior Electrical Inspector of Factories): It seems only a little time since I was asked to open the discussion on Mr. Strachan's paper on "The Design and Application of Flameproof Lighting Equipment," and when you were kind enough to repeat the invitation, I wondered whether anything further could be found to say.

A glance at the paper by Mr. Palmer and Dr. Harper was, however, sufficient to dispel any such misgivings, for its scope is very wide indeed. There are, in fact, two papers, either of which could well have stood by itself in its own right.

The authors refer to Reg. 27 of the Electricity Regulations in its bearing on the fire and explosion hazard, and it is perhaps a little significant that this regulation also requires precautions to be taken where electrical apparatus is exposed to weather, dirt or corrosion. The paper will in fact be valued as much for the information on corrosion-resisting methods as for the sound advice where hazardous areas are concerned.

Turning now to the paper, there is a reference under Section (1) to outdoor installations, and the increasing tendency to operate plant in the open, modern oil refineries being examples of this practice. While the effect is to lessen the chance of an inflammable concentration occurring, exposure to the weather brings about other problems, and thus the authors' reference to anti-corrosive measures is a useful supplement to their treatment of the fire and explosion risk.

I was glad to see the reference to the question of the persistently inflammable atmosphere because, apart from the toxic risk, it cannot be too strongly emphasised that no electrical apparatus, flameproof or otherwise, should be installed in such conditions. The reason is that it takes two to make a quarrel, i.e., there must be an inflammable concentration and some means of ignition. Normally, the chance of these two factors being present simultaneously is small, but if one is present all the time the risk of ignition is greatly increased. Now, ignition may occur from failure of the FLP apparatus (which is remote), from high temperature induced by an earth fault, or by friction.

The authors' reference under Section (2.1.1) to the tendency of vapours to convey flame over a considerable distance reminded me of an occurrence at Mitcham when methylated spirit vapour, expelled from a factory, was ignited by cottage fires some distance away, the flame travelling back to the works and causing a disastrous explosion.

More recently, vapour leaking from a petroleum gas-holder whose water seal had blown, was carried by the wind and ignited by a furnace 75 yards distant. Six men

in the path of the flame, which caused a flashback to the gas-holder, were seriously burned.

The basic research work done by the E.R.A. and by the S.M.R.E. is mentioned, and you may be interested to know that during the visit to America of a British delegation to the I.E.C. Conference on FLP design, of which I was a member, we were able to convince the Americans that our basis of assessment of the safe gap was well founded.

The authors say that prior to 1940 data had only been established for methane. This is scarcely doing the Research Authorities justice since, for example, work on Towns Gas, begun in 1930, was published in 1936. In addition, most of the industrial gases were done before 1940. Even acetylene with all its difficulties, was the subject of an E.R.A. report in 1939.

In discussing the light available from FLP lighting fittings, the authors dismiss the fluorescent lamp as heavy and expensive. Certain types certainly are heavy, but there are lamps available in which the tube is enclosed in an acrylic cylinder, and these are much lighter and the light emission is good.

In the same connection, the authors tilt at the temperature limit for FLP lighting fittings. This question has been reviewed by the responsible committee from time to time, and it should be noted that while the temperature limit was based on that in the Cellulose Solutions Regulations there are other reasons for restricting it; among them is the desirability of preventing cable faults such as might be caused by overheating, and which might lead to hot spots in the flameproof enclosure.

The question of incendive frictional sparks where light alloys are concerned has latterly received a great deal of attention at Buxton, and the risk arising with alloys with a high magnesium content is pronounced. It was necessary some time ago to make a decision on the point, and apparatus composed of light alloys in which the magnesium content did not exceed 1 per cent. is accepted. This allows most of the recognised alloys to be used.

I am glad to see that pressurisation has received some notice. This system is coming into extensive use where the excluded gases, such as hydrogen and acetylene, constitute the risk, and also for special apparatus which has not been certified as FLP. There is, however, a good deal more in the technique of its application than is generally supposed, and the design and proper use of the pressure relays necessary to monitor its function should be given careful attention. In some cases, where, for example, a dangerous gas like acetylene is concerned, it has been found desirable to pressurise with nitrogen. Let no one suppose, however, that the cost of an extensive pressurised system is necessarily less than that of a flameproof installation, since the saving on the equipment might well be balanced by the cost of the plant for supplying and drying the air and by the running expense.

The important principle of segregation is referred to and the authors describe some of the precautions necessary. Where non-flameproof motors drive machinery through a dividing wall, the risk of gases diffusing into the motor room can normally be prevented by slightly pressurising the room, the air, of course, being obtained from an uncontaminated source.

There is no end to the good things in this paper, and the authors have not forgotten the important subject of dusts. Under Section (2.2.1) at the bottom of p. 2, it might perhaps be pointed out that Reg. 27 of the Electricity Regulations also applies to this risk.

There is, as the authors say, no British standard for dusts, but the meeting may care to know that a specification prepared by the Explosive Transport and Storage Committee, which represents Service interests in such matters, is extant.

From their remarks under Section (2.2.2), it may, I think, be inferred that the best way to avoid dust explosions is to prevent inflammable dust clouds from being

produced and this, incidentally, is typical of Factory Act recommendations, as distinct from practice elsewhere. In America, for example, they go to great pains to establish the lower tolerable danger limit, while we try to eliminate it.

In Section (2.2.1) the use of explosives proper is referred to, and it may be of interest to note that the use of flameproof equipment is in general not recommended for this risk, since ignition may be from the inside of the fitting to the outside, transmitted by thermal conduction by a train of explosive dust through the gap in the flange. Totally-enclosed dust-excluding apparatus is recommended for this purpose, flameproof equipment being reserved for Group 15 explosives, which are carried in an inflammable solution.

The ignition energies of some of the explosive dusts are much lower than those of ordinary industrial dusts; for example, starch-dust requires 40 milli-joules for ignition, sulphur 15 milli-joules, and aluminium and magnesium each 20 milli-joules, whereas a sensitive initiator, like lead styphnate, requires only 10 micro-joules.

Finally, we come to the recommendations, and I would venture to add one other item, and that is the desirability of research work being done on non-metallic materials for the construction of FLP apparatus, with the object at once of meeting the corrosion difficulty and avoiding the risk of incentive sparking that arises where light alloys are concerned. This would have an important application in the case of portable apparatus such as FLP handlamps, where there is, of course, a considerable risk of frictional sparks, while it would at the same time lessen the risk of shock. It may not generally be known that the E.R.A. have in hand an extended programme of research, and work on the application of insulating materials for FLP construction is among its most important tasks.

MR. H. EDMONDS BROWN: The authors very rightly draw attention to the Electricity Regulations and emphasise the aspect that *possibility* and not necessarily actual *presence* of danger is the criterion of use of approved equipment. This accounts for the large numbers of flameproof lighting fittings found in oil industry plants.

The authors refer in Section (2.1.2) to the absence of light control in many flameproof fittings. Whilst this may be true of earlier fittings I would suggest that it is not so true of the modern fitting with its internal reflector and prismatic refractor. The engineering approach to the design of such units results in satisfactory fittings. With mounting heights of 20 ft. or more it is fairly obvious that tungsten lamps cannot give the illumination levels necessary without exceeding the present temperature rise limitations. It seems therfore that flameproof fluorescent lighting fittings are the answer; their cost is at present the main factor against their use.

Research and a certain amount of publicity has been given to the possible hazard of ignition from sparks produced when aluminium alloys are struck and it is now suggested in Section (2.1.2) that flameproof aluminium alloy fittings may be prohibited. I understand that prohibition of aluminium alloys is at present restricted to the coal face and I consider the suggestion that aluminium alloy flameproof lighting fittings might be prohibited elsewhere should be emphatically denied, unless, of course, it is the case.

In the oil industry more and more plants are being erected in the open and lighting of such units presents a problem. From the weather aspect I think the obvious solution is weatherproof/flameproof fittings, certified types of which are now available. Whilst the greasing of flanges of standard fittings is often suggested as a means of preventing ingress of moisture, it is interesting to note that this method is not always satisfactory. Some failures we had were found to be due to dust collecting on flange faces before they were bolted up. A solution was found in smearing the flanges with grease, bolting up immediately and then painting round the outside edges of the flange.

The authors in Section (3.2.4) refer to maintenance and I do agree that maintenance must be adequate and regular. Inspection only when lamps fail is not enough.

We must not overlook the wiring installation which terminates at the fitting. We have found conduit installations most unsatisfactory due to moisture collecting and causing failure. In consequence, lead-covered armoured cable is frequently used and for flameproof installations requires a seal at the fitting. As a self-contained sealing unit with an E.T. thread is available I suggest that certification of lighting fittings should cover this method of entry just as it covers "Pyrotenax" entry in many cases.

I think we all welcome any effort that is made to record these problems and how they are dealt with in practice, because only in this way can we obtain safe and efficient lighting installations.

MR. D. A. STRACHAN: I would like to congratulate the authors on what I am sure will prove to be a most valuable reference paper on the subject.

The paper makes a plea for the acceptance of a further class of flameproof lighting fittings which would be designed to meet less stringent temperature test requirements, but I feel that this course might introduce one major problem. For instance, there could be no absolute guarantee that fittings designed to operate at a higher temperature would not be inadvertently installed in situations where fittings of the lower temperature group were demanded and this would seem to place an added responsibility on the user. I would like to have the authors' views on this particular aspect.

The authors stress the importance of regular and efficient maintenance of all lighting equipment situated in hazardous or corrosive locations. For this reason, I would like to endorse the point made in the paper which emphasises the need for such lighting equipment to be readily accessible for maintenance purposes.

The paper refers to the possible use of an acrylic plastic, in place of glass, as part of the flameproof enclosure for Group I fittings and perhaps the authors could say whether this material is likely to be acceptable for fittings certified for use in Group II conditions, bearing in mind that this Group embraces various industrial solvents.

MR. J. COWAN (H.M. Principal Electrical Inspector of Mines): I wish to add my congratulations to the authors for a paper which must prove a most useful contribution to the knowledge of the science and practice of lighting in industries other than mining. I would like, however, to offer comment on a number of points in the paper.

With reference to the section dealing with the division of inflammable and explosive media into three groups, I would suggest a sub-division into (i) liquid and (ii) vapours and gases. Flameproof enclosure offers a useful safeguard against risk of ignition with respect to certain vapours and gases but *not necessarily liquid*. A certificate for Groups II and III may be invalidated if the apparatus is immersed in inflammable liquid, or if such liquid falls on or is sprayed upon the enclosure. I suggest the authors make this point clear.

Reference is made to B.S. 229—flameproof enclosures. The sub-committee, of which Mr. Mann and I are members, has just completed the revision of this British Standard and the draft has gone out to industry for discussion. I suggest members study this draft carefully.

The surface temperature of flameproof apparatus has also been considered. It must be appreciated, however, that the granting of a flameproof certificate for, say, Group II must be related to a maximum temperature laid down to apply to the vapours and gases in this group. The maximum temperature rise specified in B.S. 889 is considered reasonable for the gases in the groups. For example, the Cellulose Solutions Regulation 1934 put the danger point for the solid residue at 180 deg. F. (82 deg. C.). This covers generally acetone and the acetates which are in Group II of Table I of B.S. 229.

Care must be exercised when using an outer acrylic cover over the toughened

glass cover of a lighting fitting to ensure that the surface temperature of the glass does not exceed 85 deg. C. Generally a free air space between the outer surface of the glass and the inner surface of the acrylic cover is essential.

In dealing with the subject of the pressurised system the term "flameproof type" is mentioned. This might be confusing and it should be made clear that such fittings are not, of course, certified as flameproof. Where air pressure is to be taken into a flameproof enclosure this has to be taken through a properly designed flameproof entry connection. For pressurising care must be taken to ensure that foul air or air fouled by gas is not deliberately allowed to enter electrical apparatus. In this system breakage of the glass bulb envelope is intended to release the air pressure and cut off the power, but it is not always appreciated that the filament, especially if low voltage bulbs are used, may retain sufficient heat to ignite gas.

There is much to be said for placing the lighting fitting outside the room or building in which gas may be present, if this is at all possible. In such position flameproof enclosure may be unnecessary and there is always the added advantage that there is not the same limitation on the amount of illumination which can be provided.

An important point mentioned by the authors is that all doors in the danger section of the building must open to the outside air. This safety measure is not always appreciated.

There is no British Standard dealing with the design of fittings which have to operate in hazardous dusty atmospheres. The use of the normal certified flameproof fitting may offer no solution. It is well known that after cutting the current off and during the cooling-off period the surrounding atmosphere is drawn into the interior of flameproof apparatus containing transformers, resisters, lamp bulbs and other heat-producing devices. Where this atmosphere is of the prescribed gas, it is reasonable to presume that any explosion which occurs within the flameproof enclosure will be contained therein. Whether such apparatus would withstand an internal explosion of highly explosive dust which had been drawn into the apparatus is a matter of considerable doubt.

As the result of comprehensive research work we have restricted the testing and certification of flameproof electrical apparatus to cover specified vapours and gases as shown in Appendix II of the Ministry of Fuel and Power Testing Memorandum No. 4 and Table I of B.S. 229.

The suggestion to use safety suspension wires in case the threads of the tubing attached to heavy lighting fittings should strip will not normally meet the case especially if the fitting is of the flameproof type. The severing of the tubing will result in the risk of open sparking, especially if the conductors are damaged. Even if there has been an accidental explosion of gas the source of leaking gas might not have been cut off. The remedy would appear to lie in the provision of pliable wire armoured cable to the fitting. A suspension chain to carry the weight of the fitting would be an additional advantage.

A few more points come to mind. The authors advise the use of grease on metal surfaces. Where this is applied to the surface of the flange joints of flameproof apparatus there is the danger of increasing the gap beyond the safe value. When the apparatus is certified as flameproof the tests are carried out with the flange joints perfectly clean; the use of grease on flange joints may invalidate the certificate.

The suggested increase in the temperature rise for the casings of apparatus must also be related to the actual use of the apparatus. Increase of temperature may result in burning injury to persons who may come into contact with the heated casing. They may fall from the floor or gantry on which they are standing and receive injuries. Another point is that increased temperature may result in damage to the lampholder

springs and contacts, and also to the cable insulation. Where used, compound sealing may also be affected.

Group IV gases shown in Table I of B.S. 229 are excluded from flameproof enclosures because we have not found a safe gap for these gases. In certain countries where apparatus has been covered for hydrogen, for example, the design has been limited to very small sizes and the joints in the structure are generally of the threaded type, and covers of the screwed type.

The painting of the external end of flange joints has been suggested but the opinion is held that when the ignition of certain gases occurs within the enclosure the flange joints do, in fact, open under the pressure developed in the resultant explosion.

MR. J. G. HOLMES: The problem of specifying the requirements for a dust-tight fitting has no general solution, but I hope that it may be broken down into separate requirements for different purposes, such as in B.S. 2516:1954 which specifies a performance test for the tail-lights of vehicles. This test is unfortunately unsuitable for industrial lighting fittings, but a technical committee of the Electric Light Fittings Association is now studying several sections of the general problem. The importance of the problem is indicated by Mr. Mann's observation that more explosions are caused by dusts than by vapours.

Protection against dust may be given by pressurisation of the fittings, so that ingress of dust is prevented or dust which breathes in is blown out. The capital cost of the equipment may be appreciable but the running cost should be small because a well-made dust-tight fitting should not lose more than one cubic foot of compressed air per hour at usual pressures.

The reference to the danger of an incendive spark from aluminium-magnesium alloys in certain rather unusual conditions emphasises the need for the proper compromise in the choice of materials. The weight of cast-iron FLP fittings may constitute a real danger in handling or in maintenance. The properties of non-metallic fittings are not yet sufficiently well explored for them to be definitely excluded from future consideration, but present knowledge indicates that the use of plastics in the wrong situation may be dangerous. Amongst the lighter alloys, aluminium seems to promise the best chance of obtaining reliable and convenient lighting.

THE AUTHORS (in reply to the discussion): The discussion has shown that the most provocative issue in this paper is that of the temperature rise permitted for flameproof lighting fittings. In spite of the authoritative comments by Mr. Mann and Mr. Cowan, we do not feel that the critics of present British practice have been answered. Our own view remains that stated in the paper—that the problem should be re-examined, remembering the severe restriction imposed on lighting standards by the present requirement. As indicated by Mr. Mann and Mr. Cowan, such an examination would have to include the effect of higher temperatures on cable insulation and lamp-holders. We cannot think that the risk of personal injury by burns warrants the considerable warning given by Mr. Cowan, as a great number of ordinary fittings have surface temperatures higher than any likely to be permitted for flameproof equipment. We are also doubtful whether Mr. Strachan's argument that changes in the temperature requirements would lead to excessive complication is really valid. Other countries operate a more flexible system without apparent difficulty and there seems no reason why such a change should constitute a major problem in this country.

Both Mr. Mann and Mr. Edmonds Brown suggest that the answer to the problem of low light output from flameproof fittings lies in an increasing use of fluorescent lamp fittings. In our experience, however, most engineers find the cost of such fittings too high to warrant their general use. It must also be remembered that the light output

of an 80-watt tubular fluorescent lamp is only of the same order as that of a 300-watt filament lamp.

Mr. Mann suggests that the weight of fluorescent lamp flameproof fittings might be reduced by using acrylic covers in place of glass, but as indicated both by Mr. Strachan and in Section (4) of the paper, research is needed to establish the resistance to crazing of acrylic components in the presence of Group II gases and vapours.

It is true, as Mr. Edmonds Brown says, that some flameproof fittings have effective light control but it is too much to claim that these are representative of modern practice; there are still many unshielded well-glass units marketed.

Mr. Mann and Mr. Holmes comment on the possible development of non-metallic flameproof fittings, and it is encouraging that the E.R.A. have undertaken a programme of research. No doubt this covers the factors mentioned by Mr. Holmes.

We are glad to learn from Mr. Mann that with the exception of aluminium alloys containing more than one per cent. of magnesium, the prohibition on the use of aluminium alloys for flameproof fittings is not to be extended to fittings used in industrial plants; this decision will be welcomed by plant engineers.

We are grateful to both Mr. Mann and Mr. Cowan for pointing out certain inaccuracies and ambiguities in the text and the necessary amendments have been made in the published paper.

Additions to the List of Members

The following applicants have been duly elected by the Council to membership in the Society and their names have been added to the list of members:—

SUSTAINING MEMBER:—

The Lodge Fittings Co., Ltd. ..... *Representative*: K. F. Hayler.
57, Albert Road, Aston, BIRMINGHAM.

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Brown, K. D. ..... 406, Woodchurch Road, Prenton, BIRKENHEAD.
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TRANSFER FROM OVERSEAS MEMBER TO CORPORATE MEMBERSHIP:—

Halfter, H. P. ..... Gold Coast Railways, P.O. Box 202, Takoradi, GOLD COAST.

Register of Lighting Engineers

The Council has accepted the following applications for inclusion on the Register of Lighting Engineers:—

Mr. A. H. Turbin. Mr. R. Croft. Mr. C. R. Mortimer. Mr. W. R. Bradshaw.
Mr. S. A. W. Doo. Mr. J. A. Davidson. Mr. J. A. Lynes.

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